Performance and Testing of the Improved Solar Electric Cooking System

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A thesis submitted to the Department of Electrical and Electronics Engineering in partial fulfillment of the requirements for the degree of
Bachelor of Science in Electrical and Electronics Engineering

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Approval

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Abstract

Different types of solar cooking systems have been used from past few years. From parabolic system to panel cookers. Each and every cooking method came up with individual and unique concepts. Several attempts are made to introduce these solar cookers and have achieved variable success. There are still some critical issues need to be solved for wider dissemination of this technology. They include affordable cost, materials to be used, appropriate location for using solar cooker, size, design and cooking time. Following these points, an improved version of solar electric stove has been designed. As it is called an improved version, this stove is structured over verification of double burner stove named “Development of Double Burner Electric Stove Powered by PV Solar Panel.” In this improved version we have brought out some significant changes involving size, material, cost, cooking time and design. Here we have presented a comprehensive study over performance based and test analysis between both stoves comparing theoretically, experimentally, and development works. We have also evaluated with previously conducted solar cookers to show how the improved one is more efficient. As it is a green approach, we intend to grab attention towards the clean energy system and how they are comfortable to use. Since 90% of people use biomass, jute, cow-dung or wood for cooking. This causes harmful effects to health and only 6% of the people have the accessibility to natural gas, primarily in urban areas. Also supply of electricity is not stable and base demand cannot be met. In fact, new gas connection to household has been suspended and electricity can be used only by prepaid system. Thus most people use cylinder gas or electric stove for cooking. Following these issues, our goal is to give sufficient amount of energy which is cost efficient, available, environment friendly and healthy.

Keywords: Solar energy, Deep Bowl, battery backup, eco-friendly, Cost efficient, improved cooking methodology.

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List of Acronyms

PV	Photo-voltaic
CARC	Control & Applications Research Center
PWM	Pulse Width Modulation
KHZ	Kilo Hertz
C°	Degree Celsius
KG	Kilo Gram
B.C	Before Christ
BCSIR	Bangladesh Council of Scientific and Industrial Research
MW	Mega Watt
LPG	Liquefied Petroleum Gas
MMCFD	Million Standard Cubic Feet Per Day
LNG	Liquefied Natural Gas
AWG	American Wire Gauge
DPDT	Double Pole Double Throw
W	Watt
AH	Ampere Hour
V	Voltage
DOD	Depth of Discharge

SOC	State of Charge
MPPT	Maximum Power Point Tracking
A	Ampere
WH	Watt Hour
MCB	Miniature Circuit Breaker
LVD	Low Voltage Disconnection
G	Gram
SSP	Stainless Steel Plate
w/mk	Watt Per Meter Kelvin
BDT	Bangladeshi Taka
P	Power
CM	Centimeter
LED	Light Emitting Diode

Chapter 1

Introduction

1.1 Outline

This project opens up a new path for cooking environment in Bangladesh. It is mainly dependent on renewable energy. This will less the pressure on natural resources. People will divert less in using natural gas. This stove is totally dependent on electricity. But our country is also facing scarcity of electricity. Thus this solution is not much benefitted towards us. For this, we are using -Photovoltaic (PV) panel providing sufficient electrical energy for cooking. It is much more environment friendly and safe to use against gas stove. This designed electric stove is comparatively better and more improved from the previous version" Development of Smart Electric Double Burner Stove Powered by Photovoltaic Energy**"**. There has been made some significant changes. For experiment, we have done field testing, analysis and payback calculation. Also we have done comparative studies regarding gas stove, electric stove along with the previous stove. In this chapter, we have explained the relation between current energy crisis situation in Bangladesh and how our project can be a solution. We also have stated the purpose of this project and the challenges we need to overcome. Each and every component are explained in detail.

1.2 Literature Review

The first paper is about the recent technologies that are imposed on solar cooking system [1]. Here, the different cookers are demonstrated on efficiency and performance ground. Based on these, three types of solar cookers are chosen- Box cooker, panel cooker and concentrating cooker. To compare among their advance technology and different purposes three types of studies are mainly performed among these three solar cookers; they are- analytical, configuration wise and comparative. The analytical part is based on social and economic acceptance over these solar cookers as to make it globally successful. Another is configuration wise which considers the different possible application depending on various design, region and performance. The three solar cookers are divided in three different segments as to structural, heat transferring, storage of energy while the sun is not available which is called thermal energy. The following three segments are also divided into different parts to demonstrate which one is more advanced. In the comparative study the three selected cookers are compared and make a conclusion on which cooker is more efficient. This study is considered over performance and cost. After the research it is concluded that concentrating cooker is more efficient comparing the panel cooker and box cooker based on performance. As the efficiency is basically determined over the heat storage system. In case of economic aspect, the panel cooker is the most affordable than the other two. The other two cookers need additional equipment like reflectors, heat storage unit which cause additional cost. To the end, some drawbacks are highlighted as to lack of social acceptance and interest and also pathways for expected solutions are explained. Also, suggestions are offered on future developments following to continue to bring more advances in solar cookers.

Another solar system cooking model based on induction describe about the overall design, simulation and practical study [2]. The proper structure includes the main power system and solar, battery charger, battery charge controller, auto switch, half bridge inverter. In this system the solar panel is connected to DC-DC converter. It shares the connection between the auto switch and battery charge controller. The grid is connected to AC-DC converter and like DC-DC converter it also shares contact between battery charge controller and auto switch. A set of battery charger is used to maintain the load leveling. To the load, half bridge inverter is used for DC-AC conversion. The half bridge inverter is connected with PWM controller and induction coil which used as a load. The current flow can be varied through induction coil by the PWM controller. In this paper, the simulation study and practical result are shown using different cooking levels. The levels are determined by switching frequency range and the selected range are from 10KHZ to 65 KHZ. The paper also shows the input and output of power levels while operating different frequency. From this analysis, the result shows, as the frequency increases the output power decreases and the current become less sinusoidal. It is clear that the system is less efficient as the power is low at above mentioned frequencies. To improve the efficiency a solution is proposed that is to use a dual mode induction heater with two half bridge inverters for low power output range and high power output range. The half bridge inverter basically utilizes the frequency to give a proper heat to the coil. However, the main discussion here is based on simulation but no practical implementation has been done yet.

Furthermore, in India a solar steam cooking system was introduced for industrial cooking and its application is basically on boiling type cooking [3]. The overall system includes Scheffler dish, reflector and storage tank. As the light fell onto the Scheffler dish, it goes towards the reflector. The reflector passes high temperature to storage tank. In the tank, water is inside it and by high temperature it converts water into steam and trough insulated piping it transfers the steam for cooking in kitchen. The provided heat is approximately 150˚ to 180˚Celsius [4].This process can cook minimum for 200 persons. Though this cooking method is cost efficient but it holds some drawbacks. It cannot be used for household appliances. This project's main focus was to utilize it for institutional kitchens. As for cost, it sometimes varies for different locations and this method depends on climate as well. During humid, dry or warm weather the receiver can capture enough sun light to transfer heat but in cold weather it is very difficult to receive the light beam.

Moreover, an insulated solar electric cooking system has been described and this system is developed with the combination of solar panel, electric heater and insulator [5]. Basically a low wattage solar panel is directly connected with an electric heater which is inside a well isolated and insulated chamber. For the insulated chamber, heat lost to the environment is minimized. Three different types of insulated solar electric cooking methodology are mentioned here which are barbeque, concrete thermal storage and boil & simmer cooking. Basically 1litre water boiling and 2.7kg of stew cooking, soup, rice and beans cooking etc. has been tested with this system. This system is also used for keeping the food items hot after being cooked. It will minimize the use of fossil fuel which is usually used at those areas for cooking and keeping the food warm after cooking. This project is implemented in two areas in Uganda one is in Gulu and another one is in northern Uganda. This project is being highly appreciated by the users. But there are some limitations which are- it cannot operate during night time as there is no electricity storage system; very low power is being produced for which it takes cooking period much more compare to the conventional cookers; there is no electricity flow controller to control the heat of the heater.

1.3Chronological Development of Solar Cooking Method

As we have seen that solar energy has played a massive and improved role in today's economy, this improvement has a long history of its chronological development. From the previous records we can see that the expenses of solar has decreased and massive progress has been done in the last fifteen years. If we look at the root of the solar energy usage method in the previous events, we might see how far they have gone. (Figure 1.1)

In around 7th century B.C, human used sun light to produce fire by using hand glass. In third century ancient people used this energy with the help of reflectors and these mirrors were addressed as 'burning mirror'. An additional procedure named as 'sunrooms' was famous in ancient ages and this idea is still used today. During the early seventeen hundred and eighteen hundred eras an attempt was made to create solar powered steamboat. Also in 1767 the first solar oven was invented by Horace De Saussure. So, it's clear from analyzing the past decades that people tried to utilize the sun power before the invention of solar panels. Later then, an initiative on the development of solar panel technology took place. One of them was French scientist Edmond Becquerel**,** who gave the thought of light could generate electricity and later this was established as the "photovoltaic effect," And later this made an influential move in PV developments. Another was in 1839 Edmond Becquerel, who invented the photovoltaic effect and in the same year the photoconductivity in selenium was also discovered Willoughby Smith. In 1883, Charles Fritts invented the first solar cells from selenium wafer. Another invention was the photon theory of light by Albert Einstein in 1905. And in 1918 Jan Czochralski analyzed on how to grow single crystal silicon. In 1954 David Chapin, Calvin Fuller, and Gerald Pearson created the first solar cell of silicon photovoltaic (PV). Following this in 1977 The United States government started research institute on solar energy. From 1981 people started to build different power plants, aircrafts, and cars by using solar energy. From the present era of 2000 solar energy was readily used in residential homes, as well as commercial and agricultural businesses. People have started realizing the different implementation of sunlight and taking interest in using it as an alternative energy more and more. Now it is encouraged to use it as household appliances and in the future it might expand [6] [7] [8].

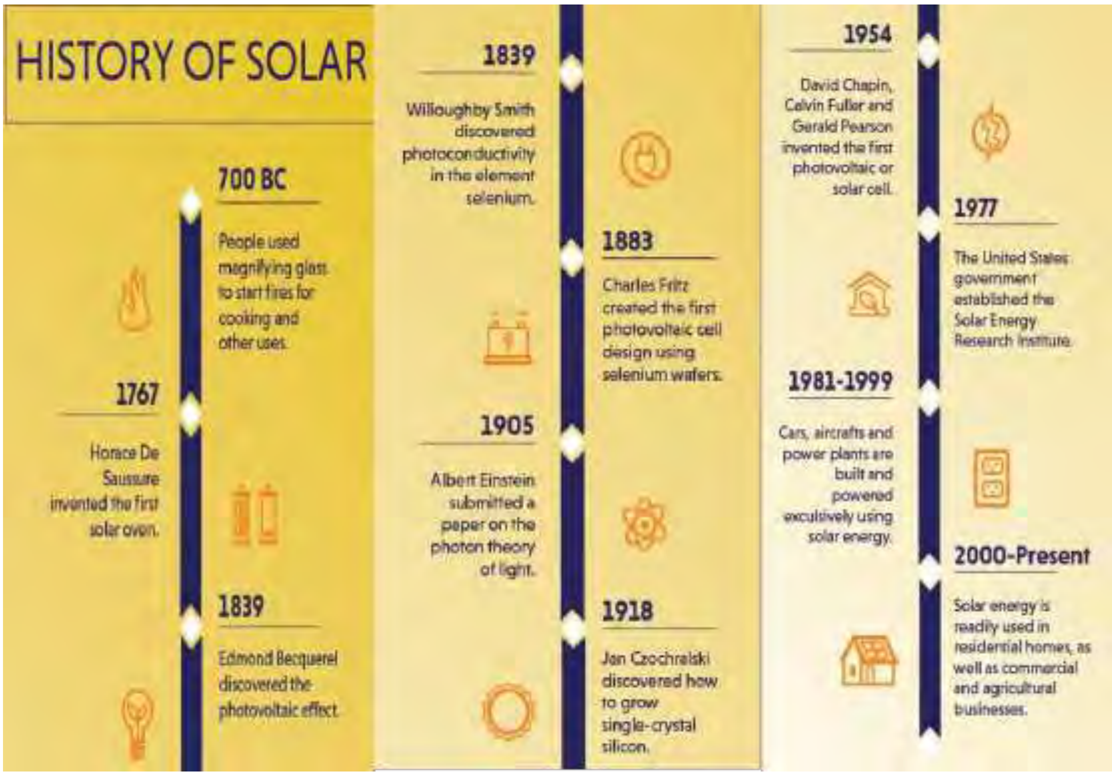

Figure 1.1: Chronological development of solar [7]

1.4Motivation of the Project

Earlier an electric cooker was designed named “Development of Double Burner Smart Electric Stove Powered by Photovoltaic Energy” [9] composed under the supervision of CARC. In this project, we originated an improved version of the previous one. And to attempt this practically, we generated our motivation from “Bohdhu Chula” innovated by “Bangladesh Council of Scientific and Industrial Research” (BCSIR) [10]. This stove has mostly targeted the rural people. Because most of them are using earthen stove. Usually these kind of stoves create smoke causing harmful effects to breathing system. To solve this issue, they have come up with an idea to add an external pipe so the smoke can go outside. This small contribution to make a huge change has motivated us to make an improved version. People have done many experiments with solar cooking. Different types of cooking styles using box type solar cooker, panel solar cooker, parabolic solar cooker but those were not possible to use for a sufficient period of time, thus it is our one of motives to make it such a way for longer period usage.

1.5 The Current Energy and Environment in Bangladesh

From statistical analysis, we can clearly see the poor situation of energy distribution in Bangladesh. In the year 2010, according to Statistic of Bangladesh Bureau, Approximately ninety percent of people get the opportunity to use electricity and only forty two percent rural people get the chance to use supplied electricity. Another survey shows about fifty nine percent people in Bangladesh have grid connection and this information is collected from 2013 statistical point of view. Though government is working on this issue by installing more electrical capacity but this is not yet enough [11]. And not only this, sixteen million out of twenty one million are household users. It shows about fifty percent connections are for household working and this measurement gives an estimation of overall Bangladeshi people. This percentage can be increased by motivating people to switch into renewable energy device. But due to high range of population it is not possible to create sufficient amount of current to produce. Again the largest energy consumers are industries, residential sectors, followed by agriculture sectors. On the other hand, Bangladesh’s electric power sector include high system losses, low plant efficiency, black out and shortage of funding power plant maintenance. It is unable to meet the demand of generation plant for past few decades [12].

In Bangladesh the natural gas is used in different cases though the lackage is continuing to grow. This resource is mainly used for producing urea, industrial work, captive power generation, and domestic chores etc. Household sector or domestic sector concludes most number of customers and it consumes about 11% of the total production of natural gas. The Bangladesh government’s priority is to increase gas supply to power plants followed by industries and fertilizer factories. Fresh household gas connection does not feature in the

Government's priority due to large scarcity of natural gas. The domestic sector was suspended of pipe gas connection from July 2010 to 2013.But it was resumed because of increasing illegal connections and repeated pleas from the affected stakeholders by diverting supplies from some power plants and fertilizer still the country is facing huge gap in supply and demand of natural gas in household sector and the government is planning to import LPG to cope with gas supply shortfall [13].

Though the demand for gas supplement is 3,300mmcfd but only 2,700 mmcfd supplies are possible in Bangladesh. Government is trying hard to increase this amount but then cost will also increase. This will be very tough for people living in developing country like Bangladesh. As a solution government is also planning to introduce LNG as energy supplement but they are very expensive; plus this would make people more dependable on imported resources.

There is no denying the fact that the environment is changing. Human are affecting the environment through their actions. People are using too much energy nowadays and using excess of it is not beneficial for territory. We use different resources as a form of energy- electricity, heat, water, etc. We use Black carbon and methane which plays the role in global warming and they are mostly used in open cooking fires. In fact fossil fuels like coal are used to produce current and burning of these fuels create huge amount of C02 in the atmosphere which also leads to Global Warming. People are using it excessively and this excess amount of energy require to be excess in assembly. Thus it would be better if energy itself is clean. But no initiatives have been taken by government or by industry to make precautionary measures for exploitation of these resources. So, now this has become a necessity to rise of a number of alternative energy sources [14] [15] [16].

1.5 Project Challenges

It is very troublesome for Bangladesh to meet the need of every people. This country is over populated. Though the attempt to minimize this shortage is carried on. For this we can think of renewing energy to use it as our requirement. Focusing on this issue, earlier another electric cooker was designed named "Development of Double Burner Smart Electric Stove Powered by Photovoltaic Energy" composed under the supervision of CARC [10]. They did it successfully but there were some points where should be improved. First of all, in this project there are two same burners. So, the cooking time for both the burner is same. Secondly, in this electric stove the cooking time is much higher. So, it would be difficult for a family to cook full day. After that, the coil of the burners was not long lasting because of the high AWG of the coil. Another problem is the short-circuit problem which damages the system when any water falls in the burner. Finally, the body was not so much improved and there was not any backup system for cooking.

Our main goal is to design an improved version of previous electric stove. In previous version, though there were two burners, it was not capable enough to capture maximum heat. So, in present version a new process as deep bowl system is introduced to capture as much heat as possible. Another goal is to reduce the cooking time compare to the previous one. This heat capture process has solved this problem too. After that, the coil has been redesigned for longer use with 16 AWG. Then to overcome the short-circuit problem, a protector is used on top of the coil. To solve the problem of long time use, the Ah of the battery has been increased and 48V power supply as a backup of solar. Finally, we improved the body of the stove for more friendly use and long lasting.

1.6 Features of the Solar Cooker

The present version of solar cooker includes PV solar panel, charge controller, battery, backup power supply, heat controller and Deep Bowl. In this system, the sun ray is converted to electricity and the power is shared between battery and load. It can operate one load at a time. A two-way switch is added in the middle of the system to choose what type of load is needed. The battery stores power for longer using or when the sun ray is not available. If necessary, backup power supply can be used at night time when the sun power is not available. There is a DPDT switch to choose the power source as requirement. The temperature of the coil provides up to 300° Celsius. This temperature can be controlled by increasing or decreasing the flow of current. Also the current required for cooking any item can be adjusted by the knob attached with the heat controller. On one side of the cooker there is a heat trapping method to cook faster which is called Deep Bowl. Deep bowl is used for cooking curry, rice, boiling. On the other hand, Hotplate is used for making any fried item.

1.7Overview of Content

Introduction and overall detail explanation are given in chapter 1 and

Chapter 2- Design and Structure

In this chapter, theoretical and conceptual studies are done related to the thesis topic. It includes solar power calculation, day time of sun, load power calculation, energy loss. What are the targets needed to meet to create this solar stove and why this stove is powered by solar power are explained here. The proposed design is shown in this chapter. Also the working process of this cooking system is clarified.

Chapter 3- Components

In this chapter, all the components have been mentioned. The selected components are solar panel, coil, battery, charge controller, heat controller. Each element is explained based on how they are used and what their purposes are. In this stove one of significant improvement is introducing a Deep Bowl which is connected on one side of the cooker. Its object is to capture as much heat as possible. In this chapter the configuration of this Deep Bowl and its using method are given. Also how it is used and what type of food item it can cook are explained.

Chapter 4- Field Experiments and Data Analysis

The purpose of this chapter is to show that the designed solar stove can meet the household needs as they are the targeted consumers. Here different experiments are done by cooking different food items and for each item cooking time has been shown. Also some thermo conductive materials are used such as: infrared glass, aluminum, stainless steel and cement layered. We used those materials for protection of the coil from water and also for safety purpose.

Chapter 5- Improvement and Comparative Studies

In this chapter, the previous version solar cooker is explained in detail and based on that where the improvements are done has been shown. As the latest solar stove is an improved version of previous stove which is "Development of Smart Electric Double Burner Stove Powered by Photovoltaic Energy" some comparison studies are also done including structure, budget, and payback calculation. Not only this, three types of cost comparison are shown. They are between LPG gas, supplied gas and previous version stove. Here other available solar cookers are also explained in detail.

Chapter 6- Conclusion and Future Research

In this chapter, the limitations of the solar stove have been pointed out. Following these limitations what are the chances to improve them and how it can be improved are explained in detail. Not only have this, the future scopes of this solar cooking system and what parts can be developed in future also been proposed.

1.8 Conclusion

As we can see using solar in cooking has been practicing from last few decades. Each cooker came up with new technique from using panel to box cooker to evacuated tube cooker. These ideas have motivated to bring new creation and method every time. They are emphasizing in cooking sector to reduce the problem of dependency on electricity and cooking gas. The only solution is to discover a substitute energy. That's why we have planned to design our stove based on solar. Our purpose is to create it cost efficient, available with energy and safe. Our People have not realized the importance of this solar technique in cooking yet as this has not earned the title as it supposed to. Although there were few odds that need to be solved and following those issues we have designed our solar cooker. Again this stove has been inspired from the previous version of solar name "Development of Smart Electric Double Burner Stove Powered by Photovoltaic Energy**".** Their work has inspired us to create another version with additional features following the stated challenges, problems, solution and purpose.

Chapter 2

Design and Structure

2.1 Introduction

In the context of Bangladesh using renewable energy like solar energy is very suitable as it is a tropical country and we get some minimum period of sun hour every day. But in order to design the solar cooking system, there is a lot of other things which are needed to take in considerations. Every solar power based system has some common major components which are a must to develop a system a design. To design a system, these major components has to be decided at first. Then the components need to be sized depending on the system's power consumption, energy losses in the system, location of the site and application of the overall system. In this chapter, the process of the designing of the system and description of the overall system along with the specification of the solar stove is being mentioned [17].

2.2 How to Design a Solar PV System

In a solar PV system, the production of electricity in the arrangement can be utilized directly or can be stored; can be connected to the grid line; can be used with other generators or other renewable energy sources. In our system, there will be battery for storage and grid as a backup option for solar PV modules. As this system is planned for making commercial, pricing and quality of the components has also taken as a factor while designing the system [18].

2.2.1 Choosing Major Components

In a solar PV system, the common major components are PV solar modules, batteries, charge controller, load, inverter (if AC output is needed), and auxiliary power source (if the system is connected with any generator or other renewable energy source). In this case, there is no need of inverter or auxiliary power source as this is a PV solar cooking System. But since the system is having the option of getting its power from national grid as a backup power source, it can be considered as an auxiliary power source in this system's case. The system's main load consists of heater coils of the stove. The average power which is needed to be produced to cook properly with the coil is 480W. In the previous version sealed lead acid battery had been use but in for this system, solar deep cycle battery has been chosen for better backup. PWM solar charge controller is being chosen as it is cheap and repairable. The ratings of the PV panels, batteries, charge controller has been determined in the next steps.

2.2.2 Sizing of the Solar PV system

At first it is essential to find out the total energy and power distribution of all the loads which is needed to be provided by the PV panel. The load of the system is the heater coil. As the construction of the coil is similar to the coil of version 1, it needs to get 480W power to get properly heated in order for cooking food items. Though there are two heater coils in the system, it has been decided to use one coil at a time to minimize the power consumption. So power consumption of the overall load is 480W [19].

After that, watt-hour consumption of the system is needed to be determined. According to survey, people use stoves or cookers 3 hours a day for cooking. So the cooker will be active for 3 hours per day on an average. So the power consumption per day becomes: $480 \times 3 = 1440$W.

Next, the energy loss of the system needs to be added in the calculation to get actual estimated power consumption. Efficiency of the system is considered as 80%. So the power consumption which has been determined previously needs to be multiplied with 1.2. Thus the panel needs to provide, (1440 × 1.2) W = 1728W per day

2.2.3 Battery Sizing

In this system, 48V is needed to be supplied to the battery; current flow to the load is 10A and need to have minimum 3 hours backup. For safety issue, this time duration is considered as 4 hours. So we need a 48V battery comprising (10× 4) Ah = 40Ah which means if 10A current is flowed through the battery the battery will run for around 4hours. In order to calculate battery rating and sizing, these issues has been considered. Previously, 20Ah lead acid battery has been used. Lead acid batteries has 50% DOD which results less power backup from the battery. For this reason, Solar deep cycle battery has been used in this case which has SOC of 20% and it is expected to enable longer usage of the battery

2.2.4 Solar Charge Controller Sizing

A solar charge controller sizing is done considering the amperage and voltage rating of the battery. The amperage rating of the battery is 10A, 40Ah and voltage rating of the battery is 48V. Thus, the system would need minimum 10A, 48V rated charge controller. In the market, there can be found different types of charge controllers. Among them MPPT charge controller and PWM charge controller is being used widely. Among them, PWM charge controller is being used for the system as this type of charge controller is comparatively very cheap, repairable and less complex circuit functions. MPPT charge controller is better but as it is expensive and hard to repair, that's why PWM charge controller has been chosen for commercialization factor [21] [20].

2.2.5 Sizing the Solar PV Modules

Generally, in a solar PV system, solar PV modules sizing is done just after sizing the solar PV system. But in this case, this sizing calculation is done at the end as the battery sizing and charge controller sizing is done at first and the PV modules would be sized according to it. From the previous sections, it is known that the load of the system is 480W, voltage is 48V, current flow through the load is 10A and power consumption per day is 1728V. In the battery sizing, battery efficiency was not considered as it was already rated as 40A by the manufacturer. But while sizing the panel, we need to consider the battery loss of the system. The efficiency of the battery is rated as approximately 80%. Therefore, the power consumption becomes = (1728 ÷ 0.8) W = 2160W. Now, this value must have divided by the lowest bright sun shine hour in Bangladesh to get better power supply and backup from PV panel. The average lowest sunshine hour in Bangladesh is 2.6 hours during rainy season. But the stove operates for 3hours on average daily which is not that much than the average lowest sunshine hour. Again, the average sunshine hour in Bangladesh is 5.67 hours. But this duration is approximately more than 2 times compare to average lowest sunshine hour. For setting up a standardized specification of the stove, the time duration here is taken as 3 hours. Thus, solar energy capacity of the system becomes = (2160 ÷ 3) W = 720W. Considering other negligible losses in the system, the value is considered as 760W. Next, two 200W and two 180W mono crystalline PV module have been connected in series in order get this 760W power from the panel [19].

2.3 Design of the Proposed System

In previous version there was used 760W for each of the burner. The current was 10.5A and the resistance was 4.5 Ω. In our latest version we are using 760W solar panel consisting of two 200W panel and two 180W panel connected in series. We are consuming these solar stoves one at a time. So, 760W is enough power for both of the burners. In this system the coil is producing around 480W power. This 4800W coil can be used for proper 1 hour simultaneously. If we assume to use the power for approximate 3hrs, the total will be 1440Wh. But the lowest average sun hour in Bangladesh is 2.6 hours, so we will get (1440Wh/2.6h) = 553.85W from the solar panel. But due to energy losses in the system we needed to setup this 760W solar panel which has been discussed previously. We will get more power during summer time and this extra power will help the system for better battery charging and backup. In the system, four batteries are being used as the storage of energy for the system, each containing 12V and total 48V is used for both of the burners. In previous version there were used 8 batteries for both the burners. In our case the total current is 10A. A charge controller of 48V 20Ah is used for each of the burners. There is also attached a heat controller to control the heat as of the requirements. Unlike previous version one side of the stove is deep bowl to capture the maximum heat possible [22]. The proposed design of the system is given in Figure 2.1.

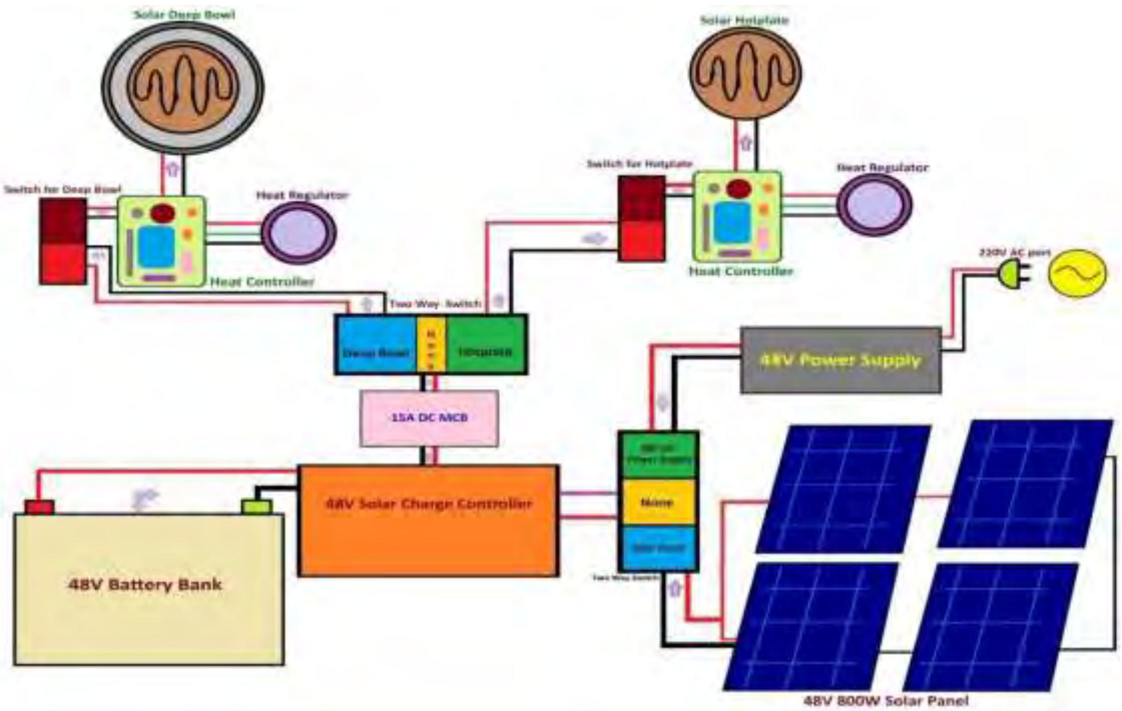

Figure 2.1: Block diagram of proposed system

2.4 Specification of Solar Stove

In table 2.1, the specification of the solar stove is given. The net weight of the solar stove is 110 KG. The overall housing is made of wood as the stainless steel costing is higher. In hot plate surface, a coil is used of 4ohm.All the cooking elements are designed to form resistor for heating purposes. We are using solar as power source. This renewable energy system is harmless to environment. We are also using 48V battery, each 12V in series to store power coming from the solar. We have used one solar charge controller of 48V and 30A.We have used a dc heat controller along with the load to control the flow of current. The control panel is displayed on the front side.

Type	**Specification**
Net Weight	110 KG (Battery Weight: 65KG)
Housing	Wood and Stainless Steel (Top Surface)
Cooking Elements	Resistance Elements
Power Source	Renewable Energy (Solar)
Voltage	48V
Power	120-1000W
Battery	48V, 40Ah, 4pcs,Solar Deep Cycle
Solar Panel	760W Mono Crystalline(Manual Maximum Power Tracker)
Solar Charge Controller	48V,30A,1pcs
Control Type	DC Heat Controller, Rheostat

Application	Kitchen
Control Location	Front Panel
Feature	Adjustable Temperature, Portable, Utensil Organizer
Burner	2(1 Deep Bowl, 1 Hotplate)
Pace Of Origin	Bangladesh
Cleaning Type	Self –Cleaning
Color	Various
Warranty	Standard one year

Table 2.1: Specification of Solar Stove

2.5 Working Principles:

In figure 2.1, the operation of the whole system is shown. There is a two-way switch called DPDT (Double pole double throw) switch. This switch decides which one will work as power source either the PV panel or grid connection. If the power is taken from the solar panel, it will go through the charge controller. The controller controls the power by charging the battery and sharing power with the load. Along with the charge controller there is a DC MCB (Miniature circuit breaker). It protects the loads from flowing huge current. Whenever excess current flows the circuit breaker disconnects both of the loads from the connection. Again, two-way switch is used to decide which of the loads will be operated, either the deep bowl or the hot plate. There are again individual switches for individual loads to turn them on. A heat controller is added along with each of the loads. A heat regulator, a switch and a load is connected to the heat controller. The heat regulator controls the current flow to the load. Similar to this, if we choose the grid connection as the main power source the DPDT switch will be turn on. The charge controller will share the power with the battery and the load. A circuit breaker will work only when huge current flows. Above DC breaker, another switch decides which of the loads to turn on. A heat controller is attached to both of the loads adding the heat regulator and also the switch. In figure 2.2, 2.3, 2.4; physical body structure is shown. In figure 2.2 the measurement and design of the outside body part of the solar stove is given. At the lowest part, there is a box length of 22 inches. In the lower part we keep the batteries. In the bottom part there are two boxes total is 22 inches in width. Inside the box, charge controller, circuit breaker and power supply connection are placed. There is a front panel height of 5 inches in length. From bottom to lower part, the height is 24 inches. In figure 2.3, inside body part is shown. As we can see on one side there is a deep bowl of 1.5 liter. In figure 2.4, the upper body part of the stove is shown. One side there is a hotplate and a deep bowl on the other side. The length is of the upper body is 36 inches and width is 24 inches [23].

Figure 2.2: Outside body part diagram of solar stove

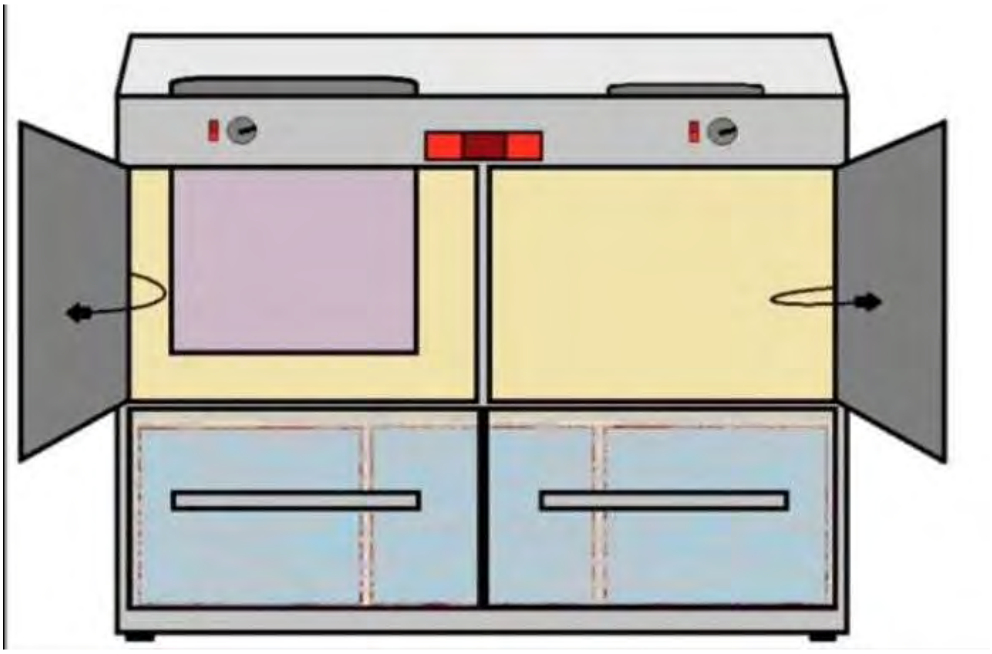

Figure 2.3: Inside body part diagram of the solar stove.

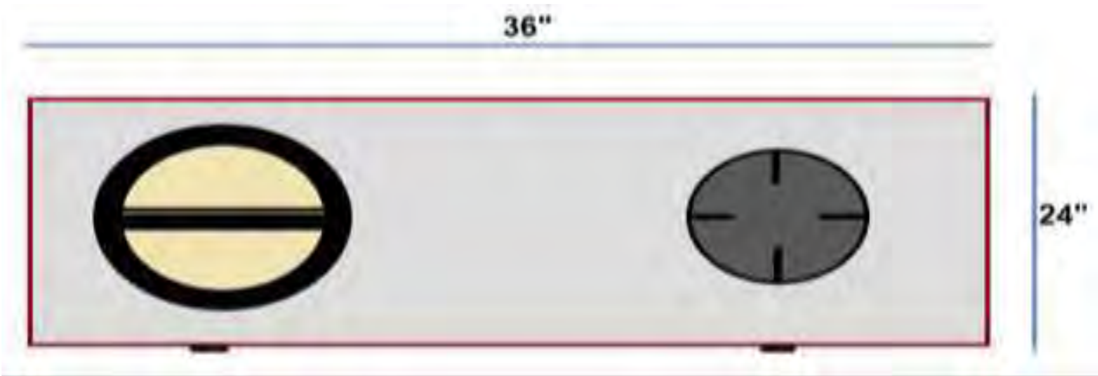

Figure 2.4: Upper body part diagram of the solar stove

2.6 Conclusion

In this chapter, the development of this solar cooking system; working methodology, specification of the stove has been discussed thoroughly. For developing the system design,

System sizing, PV panel sizing, battery sizing, Charge controller sizing has been done at first and then the system has been designed according to it. After designing the whole system, the solar stove has been developed according to the stove specification. Finally, the working principle of the whole system and also stove itself has been described thoroughly in this chapter.

Chapter 3

Description of the System Components

3.1 Introduction

This chapter is divided into ten segment including overall development comparing the previous stove. The body has been improved, both internal and external design has been changed. Also the components that we have used explained in detail step by step. We have mentioned the additional parts that we have newly included in our stove.

3.2 Solar Panel

In this system, the most major component is solar panel. It is the main energy source of the system. It takes light energy from the sun and it turns the light energy into electrical energy. In this section of the paper, different types of solar panel have been described along with the suitable type of solar panel for the system.

3.2.1 Types of Solar Panel

If this is possible to use this sun ray as a resource, then it will be very productive and systematic for future and further. In fact it will be easier to create such promising prospects to construct, utilize and reserve. But the adjustment of this solar panel and types of it dependent on suitable area, location and climate. In tables 3.1 different types of solar panels are shown and which type will be a best option according to our climate is shown later [24].

Type	**Energy Efficient Rate (percentage)**	**Merit**	**Demerit**
Mono crystalline Solar Panel	Twenty percent	High potential energy and high longevity	Costly
Poly crystalline Solar Panel	Fifteen percent	Low cost	Life longevity low and take less room to

			adjust and work
Thin-Film: Amorphous Silicon Solar Panel	Seven to ten percent	low cost, comfortable to use	Low longevity
Concentrated PV Cell	Forty percent	Very productive and potential in case of efficiency	Solar tracker is needed and also a cooling arrangement is required

Table 3.1: Types of solar

3.2.2 Mono Crystalline PV Solar Panel

Solar PV panels are relatively newer technology compared to the others. It provides clean green energy. The life span is incredibly long and very much efficient in summer time. It can cover around 60% of household energy needs. It does not damage easily and can cover the needs of appliances with high energy consumption. The advancement in technology and increased manufacturing scale have not raised the cost. But it has increased the reliability, and the efficiency of photovoltaic installations. In our case we are using Mono Crystalline PV solar panel to cook because it has high efficiency rate and high life time value. It set at 60- degree angle for perpendicular radiation shown in figure 3.1. As we need 500W in the load, we used 4 panels each 200W which makes 800W. We took 800W from panel because of some power loss in the system. This PV power is used simultaneously for the load. Our designed system will use this PV cell to create electricity to power up the stove with the availability of an energy storing battery. So, the cooker can be used after sunset [25].

Figure3.1: Mono Crystalline PV solar panel

3.3 Structure of the Stove Body

In figure 3.2 is shown the structure of the body. The surrounding part is made by wood ad painted white. Four handle are attached onto the body to open the boxes. Inside the box there are two shelves shown in figure 3.3. At the lowest part four batteries are kept and at the bottom a charge controller and grid connection are set. The battery connection is attached to the battery side of the charge controller. From the back of the stove body, panel connections wires are brought up. Beside the charge controller, grid connection set up is attached. This connection is bought from the socket. At the top of the box two heat controllers are attached. At front side a panel has been designed. In the middle, a two-way switch is attached to select the loads. There are two loads; one is hot plate and other is Deep Bowl [Fig: 3.4]. Two knobs are added to control the flow of current individually. As shown in Figure 3.4, the surface is covered with tiles. There are two holes to adjust the hot plate and Deep Bowl. The coils are hold by plate to fix into the hole.

Figure3.2: Stove body

Figure 3.3: Internal design of the stove

Figure 3.4: Upper design of the stove

3.4 Configuration of Coil

The coils which are used in AC stove usually the wattage rating is in between 1500W- 3000W. However, the coils that we are using are Nicrome coil designed in such a way that the wattage rating reduces to 500W from 1500W shown in Figure 3.5. That means the coil will initially heat at 500W and as well to use. Thus, it is cost efficient and easily available in local market. The coil resistance is 4Ω and the total current will flow through the coil is 11A approximately. Hence the power will be for each burner (11^2 ×4) = 484W. The voltage of the stove is confirmed to be 48V.This designed coil is attached in the mud plate. There are two holes on the plate to fix the coil.

Figure 3.5: Configuration of the coil

3.5Deep Bowl

A Deep Bowl is an implementation of countertop electrical cooking system used to simmer at a lower temperature than other cooking method. Our main goal is to reduce the cooking time. We can work it out by capturing as much heat as possible which can be accomplish by using new cooking methodology. In our solar stove system, we have designed a Deep Bowl using a 1.5 liter; 1000 Watt rice cooker shown in Figure 3.6. It is round shape cooking pot made of metal. The lid is made of glass and used to cover the edge of the pot. This Deep Bowl is safe to use. The lid is placed onto it and turns the heat on. It prevents the warm vapor from escaping. It works as a cooking container with thermal energy reservoir. The coil we used to heat the cooker is same as the hotplate one. We opened the bottom part and cut the region to place the designed coil inside it. This coil is also 4 ohms. The coil connection goes through the two-way switch. A metal bat is used underneath the coil to place it in a fix position. We used the lid to cover the pot and this method helps to cook faster. Variety of food items can be cooked in this Deep Bowl. The both can be heated maximum 300degreeCelsius.

Figure 3.6: Deep Bowl

3.6 Battery

We used solar deep cycle battery as it is feasible for off-grid usage. Its performance is predictable and highly reliable, compare to lead acid battery. In Previous case, 2 sets of batteries were used. However, we have used 1 set of batteries consist of 4 batteries with 12V each shown in Figure 3.7. The batteries are connected in series so that we can get 48V. This battery connection goes through the charge controller. As we used deep cycle battery, it generally stores energy which generated by solar panel. It provides power at a steady state over a longer period. Assuming the battery is fully charged, then it will have the capacity of 40 Ah (Ampere Hour) which means the battery can provide 480 Watt for one hour without other power source. Basically it refers the amount of energy a battery can store or discharge. It measures the time it takes to discharge before recharging. The depth discharge limit of this battery is 20% with electrolyte. The main difference in deep cycle battery is structural. The lead plate is thick, active with high density. The previous battery which was used in version 2 was only 20Ah with 50% discharge limit. Though the price of this battery is a bit higher than the lead acid battery, it is more feasible to use. The specification for both of the batteries are given in Table 3.2.

Battery (version 2)	Battery (version 3)
Sealed Lead Acid	Solar Deep Cycle
20Ah-20V	40Ah-12V
50% discharge limit according to SOC(state of charge) chart	20% discharge limit according to SOC chart
Maintenance fee	With electrolyte
Price- 3500BDT	Price- 5600BDT

Table 3.2: Difference between version 2 and version 3 battery

Figure 3.7: Battery

3.7 Charge Controller

A solar charge controller is a controller used to protect the battery from over charging and discharging. It controls the flow of current to the battery for damage reduction. It keeps the voltage within the rated standard of the battery. For off grid solar system, a charge controller is necessary for its protection. We are using one PWM (Pulse width Modulation) charge controller in our cooking stove which is shown in Figure 3.8. The rating of the charge controller is 48V, 30A, LVD (Low Voltage Disconnection) as optional. When battery power goes down below 25%, the charge controller will disconnect for the safety of the battery which is the job of LVD. There are total six connections in this controller, they are: + Panel, -

Panel, -Battery, +Battery, -Load, +Load. The connection of the Solar PV panel and the AC-DC power supply is connected with the +Panel and – Panel port through a DPDT switch point. From the four 12V batteries connected in series, positive point of the first battery is connected with + Battery and negative point of the fourth battery is connected with – Battery port of the charge controller. The load side is connected with the +Load and –Load port of the controller. When the load is off, the charge controller share power only with the battery from the PV panel. But when the load is on, the charge controller shares the power with battery and also the load. There are five indicators to shown the condition of the battery. The indicators are - charging, full charge, medium charge, low charge and load out. When battery is fully charged it indicate only green, for medium and low charge it indicates yellow and red. If battery takes charge from solar panel or grid the charging indicator will show and at LVD the load out indicator will blink.

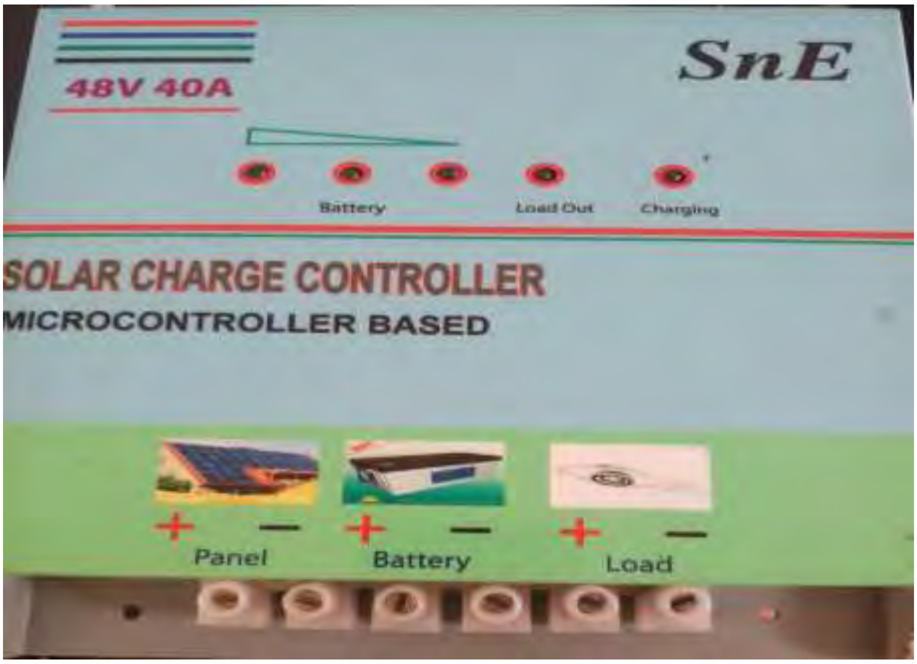

Figure 3.8: Solar charge controller

3.8 Heat Controller

Another major component of the stove is heat controller. It can increase and decrease the heat of the coil. This controller takes power from the load side of the charge controller and the two sides of the coil are connected to it. A knob is there to control the current of the coil. As the heat of the coil is proportional to the current flow (Figure3.9). In this system, a variable resistor was supposed to connect to vary the current but the current is too high. Therefore, to control it, pulse width technology is used. The controller's PWM frequency is settled at around 25KHZ and the speed range can be adjusted between 0%-100%. This heat controller consists of 20A, 48V DC. The controller uses 0-5V as an external voltage. By using this voltage, it is feasible to regulate the heat while cooking foods. The average current through the heat controller's input side is 10A [26].

Figure 3.9: Heat controller

3.9 Backup Power Supply

As the system is connected to the national grid for backup, an AC-DC power supply has been attached with the system. In Bangladesh, voltage rating of the national grid is 220V with AC current supply. But in our system we need 48V as our rated voltage with DC power supply. The AC-DC power supply converts the AC current into DC current and turns 220V into 48V with the help of the potentiometer which is attached to it. Input of the power supply is connected with the national grid and the output of the power supply is connected with the charge controller through a DPDT switch. This switch enables to choose between using PV panel or national grid as the power source.

Figure 3.10: Backup Power supply

3.10 Conclusion

In this chapter all the major components of the solar cooker have been described. The major components of the system are solar PV panel which is the main power source; structure of body which has been modified and improved compare to the previous version's cooker body; coil which is the main source of the cooker and this coil is the main load of the system; Deep Bowl which traps heat inside a deep boiling system to reduce the cooking time; Battery which is used as the power storage of the system; charge controller which is used for preventing damage from over flow of current and discharging; heat controller which is used to regulate the heat of the coil and finally the AC-DC power supply which is used as the backup power source of the system for night time and for during bad weather. Further improvement of the solar cooker will highly depend on improving these component's type and quality.

Chapter4

Field Experiments and Data Analysis

4.1 Purpose of the Experiments and Analysis

The purpose of different experiments and analysis is to show if the cooker is suitable for home appliances. The target is to use this solar cooker for inside cooking. The analysis has been done through cooking different food items showing cooking time duration, if the timing is close enough compare to other available appliances. Also it shows the quantity of food it can produce, power sharing between battery and panel, battery discharge rate. For experiment, two types of tests are performed. In the solar cooker, two heat controllers of 20A are used. For test results, two 15A heat controllers are also used. This test is performed to show which one is better. Different conductive materials are also used to show the cooking time differences between regular hot plates. Also to identify which conductive material can transfer heat faster. This chapter is divided into seven segments. Each segments explained in detail.

4.2 Planning of the Field Test Analysis

To test and analysis a planning chart is introduced in Table 4.1, to show what type of tests will be performed and to complete each task step by step in an organized way. The chart is shown in the following-

Test Name	**Details**
Coil and Deep Bowl testing	Need to check the performance of the coil and Deep Bowl while cooking
Test the food and cooking time	This test is to check the cooking time and if the stove can cook the required amount of food
Selecting cooking item	To check if the stove can cook all kinds of food

	item
Thermo conductive plates	This test is done to check cooking time using different plates
Selecting conductive material	This test is needed to check which material has better conductivity
Using two different heat controllers	Two types of heat controllers are used. One is 20A and the other is 15A and this test is done to show the current flow differences.
Battery discharge rate	This experiment is done to show the battery discharge rate without PV panel
Testing heat sink of heat controller	This experiment is done to show an approximation of how much heat the heat sink can absorb

Table 4.1: Planning chart for field test analysis

4.3 Experiment with Food Items

In this segment for field testing, different eatable items have been cooked both in Deep Bowl and hot plate. As for item, daily food products like - rice, egg, pulse, fish, vegetable and meat are selected. All these experiments are shown in figure [4.1- 4.11] and detail of each experiments are shown later.

Figure 4.1: Cooking rice in Deep Bowl as field test (without using inner lid)

Figure 4.2: Cooking rice in Deep Bowl as field test (with the inner lid)

Figure 4.3: Cooking Ruhi fish on hot plate

Figure 4.4: Cooking lentil in Deep Bowl as field test

Figure 4.5: Cooking egg on hot plates field test

Figure 4.6: Cooking tortilla on hot plate as field test

Figure 4.7: Cooking chicken in Deep Bowl as field test

Figure 4.8: Cooking red amaranth in Deep Bowl

Figure 4.9: Cooking beef on hot plate as field test

Figure 4.10: Cooking noodles on hot plate as field test

Figure 4.11: Boiling egg on hot plate as field test

4.3.1 Description of the experiments

As shown in the figures above, the chosen food are common items. Some items are cooked in hot plate and others are in Deep Bowl. At first 500 gram of rice is cooked with inner lid [figure 4.1]. Another experiment is done with rice, this time with the lid [figure 4.2]. Then 1 kilogram of ruhi fish [figure 4.3] is cooked. This experiment is done in the hotplate only. For next testing, 250-gram lentil [figure 4.4] is cooked in rice cooker and fried egg [figure 4.5] in hotplate. Another item is also cooked in hotplate which is tortilla [figure 4.6]. To cook in the Deep Bowl, 1 kilogram of chicken [figure 4.7] and then red amaranth [figure 4.8] is cooked. The last experiment is to cook 600 g beef [figure 4.9] using pressure cooker. This time hot plate is used as load. In figure 4.10 and 4.11 noodles and egg were cooked as field testing and as load we used hot plate.

4.3.2 Cooking Time Duration of the Food Items

As given in above figure 4.1-4.11, all the cooking items are shown and in Table 4.2 cooking time for different cooking items are illustrated. The followings are given below-

Cooking item	**Hotplate/Deep Bowl**	**Cooking time**
Rice (500gm)	Deep Bowl without inner lid	40minutes
Ruhi fish (1kg)	Hot plate	30
Lentils (250gm)	Deep Bowl	30 minutes
Egg fry	Hot plate	10 minutes
Tortillas (2)	Hot plate	8 minutes
Chicken (1 kg)	Deep Bowl	1 hour 5 minutes
Red amaranth	Deep Bowl	20 minutes
Rice (500gm)	Deep Bowl with inner lid	34 minutes
Beef (600gm)	Hot plate	1 hour 10 minutes
Noodles	Hot plate	09 minutes

Boiled egg	Hot plate	15 minutes
Tea	Hot plate	12 minutes

Table 4.2: Cooking time duration of different food items

4.4 Thermal Conductive Materials

Thermal conductive material is one kind of a material which has the ability to transfer heat. Different materials have different thermal conductivity. Usually materials with high conductivity transfers heat at high rate. In this segment what type of conductive plate has been chosen and the necessity of this plate are explained in detail. Here two types of materials have been mentioned based on cost and availability.

This experiments done using thermal conductive plates and the purpose of this test is-

First, to decrease the chances of short circuit as the coil plate surface is always open. If any liquid substance falls over the plate, the coil may not work properly and will get damage.

Second point is to find such material whose conductivity will be best to transfer the maximum heat. For this test five types of conductive materials are selected. They are-

1) **Infrared glass plate**
2) **Aluminum plate**
3) **SSP (Stainless Steel Plate)**
4) **Cement layered plate**
5) **Mica paper**

1) Infrared glass plate: The infrared plate is cut in equal diameter of the coil and the diameter is approximate of 3cm. It is put on the surface of the coil as to reduce short circuit. Another concern is to choose this plate as it is effective to transfer heat. This plate is made of ceramic and it can resist thermal shock up to 700 degree Celsius. Also it does not expand if heated unlike other materials. The infrared plate is shown in figure 4.12

Figure 4.12: Infrared glass plate

(2) Aluminum plate: This plate is also cut in equal to the coil as to give protection for short circuit problem. As for heat transferring, after copper aluminum has the highest thermal conductivity which is 205w/mk and its application is cost effective. The thickness of this plates less than the infrared plate. Thus this plate will heat up faster and transfer heat faster. Moreover, as it is good heat exchanging system, aluminum cookware is used in household. The figure of aluminum plate is shown in figure 4.13-

Figure 4.13: Aluminum plate

(3) SSP (Stainless Steel Plate): This material (figure 4.14) is chosen as it is used in many cook wares. From the experiment (Table 4.3) it is clear that stainless steel is less conductive and poor ability to transfer heat compare to aluminum. It takes much longer to conduct heat away from the source. Another problem is, after long time use the plate gets burn. This plate might help to protect the coil from getting damage but it will take longer time to heat up the food. In fact, stainless steel mostly used for its heat resistance capacity. So this plate is not a solution.

Figure 4.14: SS Plate

(4) Cement layered plate: This plate is made basically covering the whole surface of the coil with thick layer of cement. One of problem with this plate is that it takes longer time to get heated. Thus this plate will take much time to transfer heat to the load. So it is not suitable for efficient cooking. The plate is shown in figure 4.15-

Figure 4.15: Cement layer plate

(5) Mica Paper: From all the plates, mica paper is very good in case of thermal conductivity. This plate is applicable for high range current and voltage. It can be a solution for efficient cooking and short circuit minimizer. But one problem is that, at one point, this plate cannot take any high range current and then it itself works as an insulator. Thus this would be tough to use this in high power for longer time. [Figure 4.16]

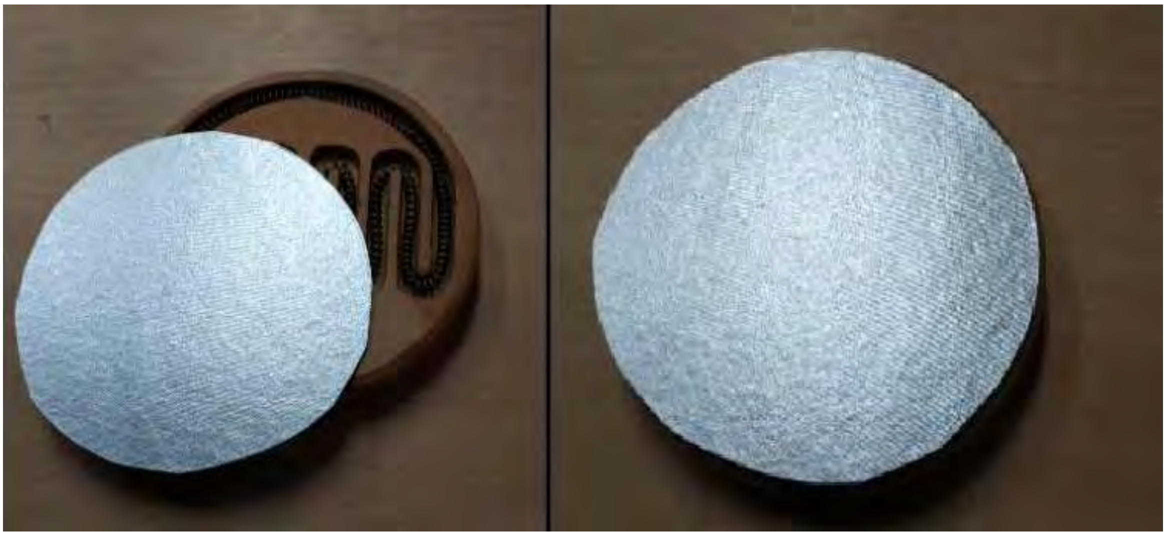

Figure 4.16: Mica paper

4.4.1 Experiment and Selection of Thermal Conductive Plates

To experiment with the selected thermal conductive plates a test has been done and as an item tap water is used. This experiment is to show if they have the capacity with good conductivity. The chart is shown in Table 4.3-

Cooking item	Plate	Cooking time (minute)
Water(0.5L)	N/A	11
Water (0.5L)	Infrared	15
Water(0.5L)	Aluminum	13
Water(0.5L)	SSP (Stainless Steel Plate)	25
Water(0.5L)	Cement layered plate	18
Water (0.5L)	Mica paper	16

Table 4.3: Experiment using thermal conductive plates

As it is seen from the chart (table 4.3), aluminum takes less time in heating. Heat transferring method not only depends on good conductivity capacity but also its thickness. The plate will heat up first and after absorbing enough heat it will transfer it to the load. From the figure

4.12 and 4.16 it is obvious that infrared is thicker than aluminum. Thus infrared will take more time to get heat up and then transfer it. On the other hand, aluminum is cheaper than the infrared glass. So, aluminum is the best option to choose and also to use for both protections of the coil and heat conductivity. However, the SS plate does not provide much solution as it works more of a heat resistance rather than heat conductance. Then the cement layered plate though protects the coil surface, it takes too much time to get heated itself and thus it will take much time to transfer it. At lasts the mica plate which has the highest conductivity among all five of them can be used as protection and new cooking methodology but the problem with this plate is that at one point it works as an insulator and cannot transfer heat. As of selection for good thermal conductive material aluminum is the best among all the five plates.

4.5 Analyzing Battery Discharging Rate

The batteries have been tested without any backup of solar power and the experiment was done for almost 3 hours. The collected data and explanation given in Table 4.4

10:22am	Initial open circuit	53.5V
	Current	0A
	Temperature	Room temperature
	Detail	At first the voltage was measured when it was open circuit and at that time no current was flowing
10:25am	Closed circuit voltage	47.3V
	Current	10.2A
	Temperature	Not measured
	Detail	The voltage dropped to 47.3

		after connecting to the load. The current was set to 10A
10:48am	Closed circuit voltage	47.3V
	Current	9.3A
	Temperature	Not measured
	Detail	Due to increase of heat a small amount current dropped
11:25am	Closed circuit voltage	46.8V
	Current	9.3A
	Temperature	Without mica plate-300C With mica plate-257C
	Detail	At this stage voltage dropped. The temperature was taken using thermometer
12:14pm	Closed circuit voltage	46.3V
	Current	9.3A
	Temperature	Without mica plate-300C With mica plate-230C
	Detail	The coil was turning red; the heat was increasing. The voltage was dropping gradually and the current was stable
12:40pm	Closed circuit voltage	45V
	Current	9A
	Temperature	Without mica paper-300C With mica paper-229C
	Detail	The thermometer probe was

		connected to the heater for 5 minutes to collect the temperatures
1:15pm	Closed circuit voltage	43.2V
	Current	0A
	Temperature	Not measured
	Detail	As the voltage dropped to 43.2V, the LVD disconnected the system from the battery to ensure the longevity of the deep cycle battery. The LVD (Low Voltage Disconnect) is set to 20% which is 43.2V

Table 4.4: Analyzing battery discharging rate

4.6 Results on Prototype Testing of Solar Stove

A prototype testing on solar stove was done to analyze its performance. In this experiment regular food items were cooked and as load both the Deep Bowl and the hot plate were used. A pie chart is shown in figure 4.17 after collecting the feedbacks.

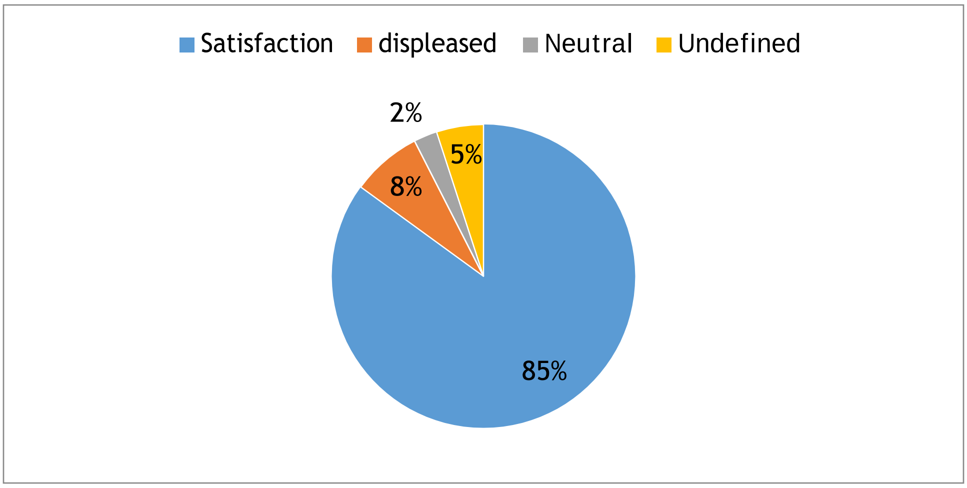

Figure 4.17: Result on prototype testing of solar stove

4.7 Survey

Two types of surveys have been done- first, to examine the acceptance of the stove to the consumers; second, to see what will be its market value. To evaluate its market demand local shops were targeted.

4.7.1 Consumer Survey

Though the stove is targeted for urban users and indoor purposes, an observation is done to see if it can meet the demand of rural people as well and so some ground points were focused in this case- willingness to pay, monthly income, daily cooking item, amount of cooking food, total family members, proper space to adjust the solar panels, currently using stove and its advantages etc. This observation was done in offline based and it is seen that most people were willing to pay 10,000-15,000 taka and they are satisfied with the functions and find it less difficult to use. As for cooking people mostly use natural gas, LPG gas or induction cookers. Advantage of these currently using stoves is that it takes less time in cooking though there is a lack of safety. On the other hand, in some area there is no appropriate place to work with solar panel. Other than that people are very much interested in using it.

4.7.2 Market Survey

The purpose of the market survey is to understand the market condition of cookers. Here some criteria are followed- season of selling, burner availability, demand of induction cookers, available price range, wholesale price. It is found that the selling rate increases during the start of every month and festival time. Maximum people search for two burners or more than two burners. And maximum shop keepers focus on gas stoves as people prefer gas stoves instead of other cookers. The maximum selling range is 5000 taka but still there is demand for higher and lower priced stoves. In whole sale price, the stove is 500-1000 taka per less.

4.8 Experiment of Analyzing the Temperature of Heat Sink of Heat Controller

In the solar stove, 20A of two heat controllers are used and as the current passes continuously through the heat controller, the heat rises and the heat sink absorbs all the heat to keep the controller cool. While absorbing this, the heat of the heat sink also rises. So, an analysis is done on estimation of how much the heat rises and for this a thermometer is used as measurement. No cooking was done for this experiment, only the load was turned on. In table 4.5, different temperatures for different time are shown. At one point the temperature stays same and does not increase.

Time (PM)	Current	Solar	Battery	Temperature(°C)
4:00	10	4.3	5.6	26
4:06	9	1.1	7.8	50
4:20	9	.5	8.5	54
4:22	N/A	N/A	N/A	54
4:34	10	1.3	8.6	55
4:47	10	1.8	N/A	55

Table 4.5: Experiment of analyzing the temperature of heat sink of heat controller

4.9 Conclusion

In this chapter, different experiments and analysis have been shown and all are explained in detail. These experiments are done based on field test analysis, estimation and prototype test. Different food items are cooked to show the cooking time efficiency. To ensure the safety of the stove different types of thermal conductive plates are used in the test. In this case five plates are selected- infrared, aluminum, mica plate, cement layered plate and SS plate. Only thermal conductive plates are selected to improve cooking methodology as well. Among five plates aluminum is the most efficient. An experiment is done for 3 hours to show how much the battery can back up without the solar power. To give an idea over current market value and consumer demand two types of surveys are shown. Also a prototype test was done to check if stove was comfortable enough to use and as shown in the above it is very smooth to use, safe and no instruction needed to operate it.

Chapter 5

Improvement and Comparative studies

5.1 Introduction

In this project, the main focus was to have improvement over the previous versions and to reduce the cooking duration. And this aim has been fulfilled and this project has a lot of improvements over the previous versions of the stoves. In this chapter, the improvements and comparisons with previous version stoves are being described. Comparison with other available solar cooking systems has also been described in the chapter.

5.2 Cost Comparison

In this segment, two of the stoves' total budgets given to show the cost comparison and the budget of both of the stoves shown in table 5.2.1-

5.2.1 Budget of the solar cookers

Overall expense to build the improved solar stove is shown in table 5.1 including the quantities of different components; in table 5.2, total expense of previous version is given-

Components	**Quantity**	**Cost per item in BDT**	**Net Cost in BDT**
PV panel	760	42	31920~=32000
Batteries	4	2500	10000
Charge Controller	1	5000	5000
Heat Controller	2	650	1300
Stove Body	-	-	4000
Coils & Mud Plate	2	250	500
Miscellaneous Cost	-	-	2200

Total	-		55000

Table 5.1: Budget of the improved solar electric stove

Components	**Quantity**	**Cost per item in BDT**	**Net Cost in BDT**
PV panel	1520W	42	63840
Batteries	8	2500	20000
Charge Controller	2	5000	10000
Heat Controller	2	750	1500
Stove Body	-	-	4000
Coils & Mud Plate and Others	-	-	500
Total	-	-	99840

Table 5.2: Budget of the previous solar electric stove

5.2.2 Cost Comparison between Conventional Cookers

In table 5.3, cost comparisons have been shown of both cylinder gas and line gas. The comparisons are done by analyzing number of cylinders used from small to moderate to big family; their per month cost and total cost per year. Beside this two more points have been given showing per month cost and total year cost of line gas.

Family size (Persons)	**Cylinder consumption**	**Total monthly cost BDT**	**Total yearly cost in BDT**	**Total monthly cost for direct gas line stove in BDT**	**Total yearly cost for direct gas line stove in BDT**
Big (8-10)	2	5000	60000	800	9600

Moderate (5-7)	1.5	3750	45000	800	9600
Small (2-4)	1	2500	30000	800	9600

Table 5.3: Cost comparison between conventional cookers

5.3 Payback Calculation

In order to do this calculation, the total estimated price of making the improved version is needed and the table is shown in 5.1. Then the present estimated price that general people have to bear in cooking needs to be inspected and this chart is shown in table 5.3. From this chart we can see practically most of the residences in Bangladesh are dependent on gas for cooking. Very few people are using induction stoves or infrared stove. Therefore, gas is more or less the main medium for cooking.

The payback calculation is done in 2 samples-

SAMPLE-1: For sample-1, the system's estimated price was computed including the panel's expenditure. Total cost for this latest solar stove: 32000 BDT + 23000 BDT = 55000 BDT. If a moderate family uses this solar stove in place of the LPG cylinder gas stove, it will take approximately 1.2222 year to get paid back the total money invested on the solar stove initially and for the small family it will take approximately a little less than 2 years to get paid back the total invested money.

SAMPLE-2: The cause behind the sample 2 is, the flats, which have already placed solar panel during the apartment's establishment thus no cost in adjusting it and this will reduce the cost. The total cost for this case excluding the solar panel is 23000 BDT. If a moderate family uses this solar stove in place of LPG cylinder stove, the total money can be paid back by approximately 0.51 years or 6 months and for a small family, the total cash can be paid back by approximately 0.76666 years or 9 months.

But for the previous version, (cost of solar panel is included) the total budget to build this was 132,000 BDT and the total money can be paid back in less than 3 years (for moderate family). For small family 4 years will be needed to get back the paid money. If the solar panel cost is excluded, then cost price will reduce to 36000 BDT and any moderate family will get back this money in less than 10 months and approximately 15 months for small family. Though during that time, expense of per unit panel was much expensive than the price right now.

From above analysis it is clear, this new improved version is much reliable in re- earning the expend money within short time.

5.4 Comparison with Previous Version Solar Cooker

In table 5.4 a comparison is shown between previous version and improved version solar stove. It shows what type of changes have been done including power, cost, implementing new methods, and body structure.

Comparable Points	**Previous Solar Electric Stove**	**Improved Solar Electric Stove**
National Grid	Not available	Available
Cost	High	Low
Power Consumption	High	Low
Cooking Time	High	Low
Heat Trapping System	Not available	Available
Designed Coil	20 AWG	16 AWG
Short Circuit Protector	Not used	Infrared plate
Battery	20 Ah	40 Ah
Overall Body Features	Wood and tin	Tiles and wood

Table 5.4: Comparison between previous solar electric stove and improved solar electric stove

5.4.1 Comparison with structural point of view

In previous solar electric stove [figure 5.1, 5.2] 760W of solar panel was used as power source which was total of two 200W and two 180W designed in series. This connection goes through the charge controller. Here two sets of 48V battery were used with each of 12V and they are also connected through the charge controller. Two charge controllers were used to operate both the coils at the same time and to charge the batteries. The previous battery was of 20Ah which is less than the latest one. The designed coil was 4.5 resistance and 10.5A of maximum current will flow and the total power will be; power, P= (10.5^2 * 4.5) W = 496.125W. In the latest version, total of 600W is provided as single load will be operated simultaneously. As to store energy, 1 set of battery is used which is total of 48V, each containing 12V. in this version two way switches have been used in two sections- one to choose which source of power will be used as per required and another is to choose the suitable load either the hotplate or the Deep Bowl. The configuration of this version include coil of 4.1ohm resistance, total current 11A and the total power is, P= (11^2*4.1) =496.1W

The power consumption of both stoves is close enough. In figure 5.3 and 5.4 a proposed design is shown of previous version and the latest one. The previous version's overall body was made of tin and wood. No DPDT switch was used as both of the loads can be operated same time. The length and width is 70cm\80cm which is a bit smaller in height than the latest one which is 30.48cm\81.28cm. The latest version is more innovative in case of design, decoration, and facility. This stove's body is made of wood and ceramic.

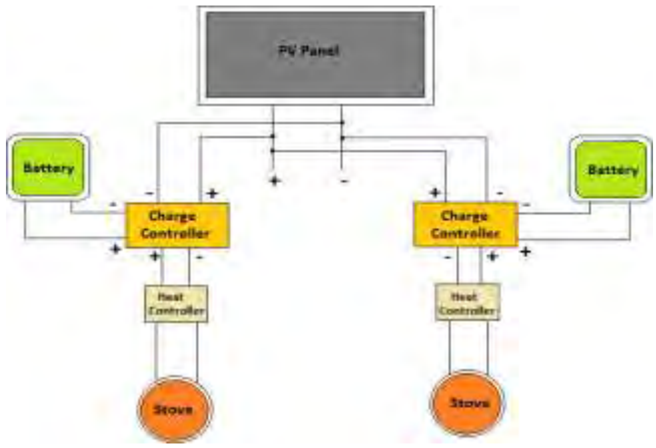

Figure 5.1: Block diagram of previous solar electric stove

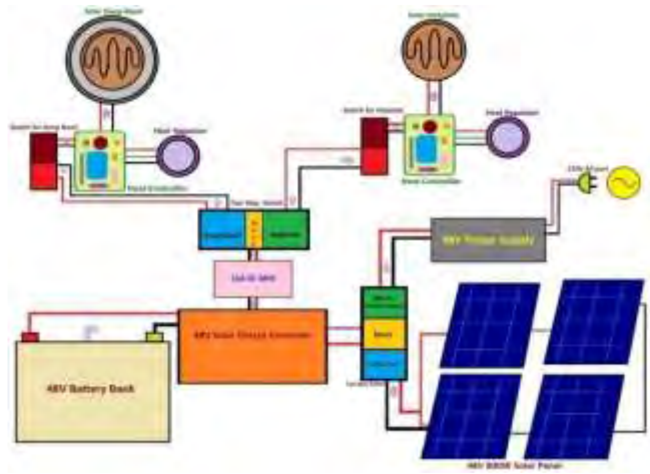

Figure 5.2: Block diagram of improved solar electric stove

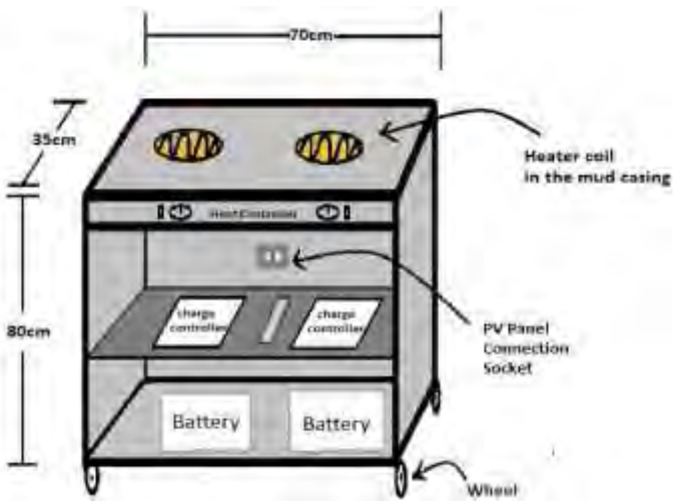

Figure 5.3: Proposed design of the body of previous solar electric stove

Figure 5.4: Proposed design of the body of improved solar electric stove

5.4.2 Comparison in Cooking Time

The cooking time of both previous version and improved version is given in table 5.5

Selected Food Items	Cooking Time of Previous Solar Electric Stove	Cooking Time of Improved Solar Electric Stove
Boiling water	12	10
Rice	35	34
Egg fry	10	10
Lentils	45	30
Vegetables	40	25
Beef	N/A	70
Chicken	N/A	65
Tortilla	N/A	8

Table 5.5: Comparison in cooking time between the previous solar electric stove and the improved solar electric stove.

5.5 Types of Solar Cooker

In the commercialized market, there are basically four classes of solar cookers in – panel solar cooker, box oven solar cooker, parabolic solar cooker, evacuated tube cooker. The panel type cooker is a box which is opened three sided. The whole box is coated with glossy material to create reflectors. The sun rays hit onto the panels and into the midpoint of the box. Next is box oven solar cooker and this is similar to panel solar cooker. Except its open side is covered with glass to create an air tight heat trap. Inner part of the box is colored with black paint to develop a heat sink. They also have shiny panel to deflect the sun rays into the heat trap. Third is parabolic solar cooker; it is shaped like parabolic satellite dishes. The dish is also coated with glossy material to make reflective. A pot is placed in front of the reflective surface. The last one is evacuated tube cookers. It is made from large evacuated glass tube encompassed by shiny reflector panel. This cooker reaches to high temperature and able to cook meat, bread vegetable and desert [27].

5.5.1 Advantages of Solar Cooker

There are many advantages in using solar cooker. As we can maintain better air quality indoors and reduce the amount of carbon monoxide emissions. Solar cookers are eco-friendly and harmless for environment and also do not cause any health injuries unlike other cooking systems using wood, kerosene, cow dung, biomass etc. these create smoke which is very dangerous for health. We can reduce the dependence on electricity, and cooking gas by using solar cookers. As we renew the energy direct from the sun, it is more available. Solar cooking is one time investment after its installation, it is free to use. Solar cooking is cost effective for a longer period of time. The quality of solar cooking is notable. Solar cooking does not burn food and change the flavor [28].

5.5.2 Comparison with other Available solar cooker

Item Name	Molten Salt Solar Cooker
Origin	Silicon Institute of Technology, Bhubaneswar, India
Technical Detail	i. Solar Concentrator ii. Water Tank iii. Phase Change Materials Tank During daytime water inside the tank become steam which is transferred to heat exchanger to produce heat. Then solar concentrator generates 800°C which is the melting point of Phase Change Material (NaCl). For this, in day time water steam is used and in night time the molten PCM is used to generate heat.
Performance	It can perform both day and night time and comfortable enough for indoor cooking. No battery storage is needed and can cook any sub continental food.

Table 5.6: Basic specification of Molten Salt Solar Cooker

Discussion: In this solar cooker there is no conversion of light energy into electrical energy. This cooker uses direct heat from the sun to solar concentrator to produce heat for cooking. Also there is an issue of adjusting the panel to catch direct sun ray. Though it produces more heat than our solar cooker, the heat of the cooker cannot be controlled properly. There is no battery to store energy for this system. But it can be used at night time with the help of its PCM. Unlike this, our solar cooker has overcome these limitations [29].

Item Name	The Hawkeye Solar Cooker
Efficiency	I. Need to charge by Solar Parabolic Concentrators 6 hours before cooking in the morning II. Can produce 150-200°C heat III. Cooking limited into roti, vegetables
Technical Details	I. Inner Storage Box (length - 56cm, width - 84.5cm, height- 58.5 cm) II. Outer Storage Box (length - 162.5cm, width -

	84.5cm, height - 58.5cm) III. Light Funnel (Length - 30.4cm) IV. 2 Arrow Reflector In this system, half pipe parabolic reflector is used to capture the proper amount of solar energy. There is a mirror shaped as 'V' and it is adjusted properly at the center of it to capture the maximum heat. This 'V' shaped mirror reflects the light between a glass panel to an absorber plate. The absorber plate stores the heat and this plate is made of plywood. This box is filled with sand and aluminum. It increases the conductivity of heat. The sand and can is covered with rice husk so the internal heat won't be able to get out.

Table 5.7: Basic specification of The Hawkeye Solar Cooker

Discussion: The Hawkeye solar cooker is a developed version of parabolic solar cooker. This system is applicable for limited cooking- roti, vegetables. It produces less heat which will take lot of time to cook. It needed to be charged for six hours before cooking. So if the sun hour is less than six hours, it will not be possible to cook that day. In our system the maximum temperature is 300°C and it can cook various types of food unlike the Hawkeye solar cooker as there is an option for slow cooking item.

Item name	Solar box cooker
Country of Origin	Sreendhi Institute of Engineering and Technology, Hyderabad
Performance	i. Mainly two reflectors can be used, but availability of four reflectors to track solar radiation. ii. Transmissivity increases as it is vertically positioned iii. Suitable for the environment and conservation of current energy
Technical Details	I. Wooden box II. Reflecting mirrors-2 III. Adjustable stand IV. Hinged joint Working Procedure – i. Work like traditional solar box cooker ii. Adds salt –sodium and potassium nitrates to use in heat storing. iii. An outer box along with glass lid iv. An inner box covers by heat trapping glass wool. v. Two reflectors are used to track the sun light and reflect it onto the glass lid and heat the salt. This will melt the salt and store the energy.

Table 5.8: Basic specification of Solar Box Cooker

Discussion: In this solar box cooker, there is an option to store energy in to an insulating glass wool for later usage [30]. But it is not user friendly to maintain the appropriate angle for reflectors and the heat cannot be regulated as per required. This system is not suitable for household use. But our system is very comfortable for household purposes. Moreover, battery is used for later use and very congenial to use. The heat can be controlled as per requirement and there is no need to do any adjustment to capture sun ray.

5.6 Conclusion

In this chapter, main motive is to show an overall study based on comparing the two solar electric stoves. This study will compare both of the stoves in different segments- cost comparison, body structure, cooking time, technical improvements, payback calculation to demonstrate how far the improvements have been done. From every analogy it is clear; the latest version is much improved. Not only this, another comparison is done between conventional cookers-cylinder gas, government supplied gas. Though the expense is less in this case but we need to keep in mind the natural resources are decreasing and will keep decreasing, thus an alternative source is needed immediately which uses an unlimited resource as power and environment friendly. This latest version meets the demand in all aspects.

Chapter 6

Conclusion and Future Research

6.1 Conclusion

After working, analyzing and experimenting for one whole year, the project has been a great success. The main goal of this project was to minimize the cooking period and to overcome the short circuit problem which the previous versions had and to make the stove more user friendly as much as possible. A new cooking method of slow cooking has been introduced by making one of the burners as Deep Bowl and this cooking method has made a significant improvement in reducing the cooking period. Another great feature of this stove is having national grid as backup power supply when there is low power coming from the solar panel. For lower power consumption and efficient usage of the stove, only one among the two burners will be activated which also proven to be functioned as per plan. The tests which has been made to use thermo-conductive materials for preventing short circuit has also been a good success. It is now visible what kind of thermo- conductive materials can be used as a short circuit reducing product. Thus this version of the solar stove has proven to be superior over all the other available solar stoves which has been previously made. And the efficiency of this solar cooking system has lead us to think about further growing and further enhancement of this project.

6.2 Future Research

Though this project being a big success, this stove needs some further improvement to make it more user friendly and sustainable. Every successful project has some drawbacks and things which can be improved. This project also has some places which may be needed to be changed or improved. Some proposal has been made in the later part in order to make some modification to this solar cooking system.

6.2.1 Project Limitations

In spite of being a well appraised project, this solar cooking system has some drawbacks which are needed to be worked out as early as possible. The PWM motor controllers which we are using as the heat controllers are not that much stable for the system. The controllers can take temperature around 50-60˚C. So when the temperature inside the chamber of the stove increases more than that, the system becomes unstable. Many heat controllers have also been changed due to it. Though we could use it for our experiments thoroughly, it cannot be used for longer periods. So to get more efficiency and sufficiency from the cooker new type of motor controller should be introduced. Further tests and experiments are needed in case for seeing the efficiency of the thermal conductive materials as using those for preventing short circuit of the heater coil. Another problem with the stove is, it is only user friendly to those who are trained to use the stove. A general public cannot understand controlling the heat by reducing current. Easier systems of indicators should be introduced in the system to make it more user friendly.

6.2.2 Proposed Future Research

From studying the limitations of the present solar cooking system, there have been made some proposals for the future development. Motor controllers, used in the auto-battery bikes, can be a good solution for the heat controllers as it can work for many hours relentlessly. For making it easier to access, a new type of PWM motor controller which has LED display to indicate the battery status, solar panel status and load level status can be used. It will enable the general public to use it more easily to know about the stove system. Another micro- controller based LED system can be developed with heat controller to let the user know about the current, voltage and temperature of the load side without using any multi meter. It will also make it more user friendly. If these developments can be made, this project will reach new height and will be highly accepted by the common people.

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